The Holy Grail of Time-Certain Development

16 June 2008

Dr. Peter Hantos
Software Acquisition and Process Department
Software Engineering Subdivision

Prepared for:

Space and Missile Systems Center
Air Force Space Command
483 N. Aviation Blvd.
El Segundo, CA 90245-2808

Contract No. FA8802-04-C-0001

Authorized by: Engineering and Technology Group

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El Segundo, California

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Cross-Program Lesson Sharing Forum

The Holy Grail of Time Certain Development

March 5, 2008

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SES/SAPD

Slide 1

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Acknowledgements

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  ❖ **Funding source**
    - Mission-Oriented Investigation and Experimentation (**MOIE**) Research Program (Software Acquisition Task)

  ❖ **Inspiration**

All I really need to know about estimation I learned in kindergarten and from Dr. Barry Boehm....

Agenda

- **Objectives**
- **Defense Acquisition Performance Assessment (DAPA)**
- **"Back to Basics" Air Force Initiative**
- **Time Certain Development**
  - ❖ The reasons behind Time Certain Development
  - ❖ Perspectives on Time Certain Development
  - ❖ Perspectives on making time a Key Performance Parameter
- **Confidence in a Software Estimate**
  - ❖ Estimating software size
  - ❖ Cone of Uncertainty
  - ❖ Life cycle phase dependency
  - ❖ Risks of cost estimation risk-reduction approaches
  - ❖ Technology Readiness Implications for Time Certain Development
  - ❖ Iron Triangle Fallacies
- **The Experts' Voices**
- **Conclusions**
- **Acronyms**
- **References**

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Objectives

- Explain the context and background of the DAPA recommendation for Time Certain Development

- Contrast acquisition management and engineering perspectives on Time Certain Development

- Explore the underlying estimation issues impacting successful implementation of the recommendation

- Emphasize software issues related to the acquisition of software-intensive systems

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DAPA (Defense Acquisition Performance Assessment)

- **What is DAPA?**

  ❖ The **DAPA project** is an integrated assessment of every aspect of military acquisition, including requirements, organization, legal foundations, decision methodology, oversight, and checks and balances
    - It is a response to a 2005 DOD Directive by Mr. Gordon England, then Acting Deputy Secretary of Defense

  ❖ The **DAPA report** is the result of this project
    - Developed by a panel lead by Lieutenant General Ronald Kadish (Retired), USAF
    - 107 experts and 130 other, government and industry acquisition professionals were interviewed
    - The full report is available at [DAPA 2006]

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DAPA Recommendations To Be Discussed

- **Budget**

  ❖ Transform and stabilize the PPBE (Planning, Programming, Budgeting, and Execution) process

    – Adjust program estimates to reflect high confidence

      – **High confidence programs defined as a program with an 80% chance of completing development at or below estimated cost**

    – Major acquisition programs would be fully funded at a level that would cover the program from **Milestone A** through the first delivery of low rate production

- **The Acquisition Process**

  ❖ Establish Time Certain Development as the preferred acquisition strategy for major weapons system development

    – Time Certain Development adds "time" as a factor critical to the discussion of the need to balance cost and performance

    – Deliver useful military capability within a constrained period of time

    – Make time a KPP (Key Performance Parameter)

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The Reasons Behind Time Certain Development

- **Tension between the DOD acquisition culture and the needs of Combatant Commanders**

  ❖ The prevalent culture is to strive initially for the 100% solution in the first article delivered to the field

  ❖ On the other hand, Combatant Commanders have urgent needs that are tied to ongoing operations

- **Making time a KPP seems to be the vehicle to express this customer urgency to the Developer**
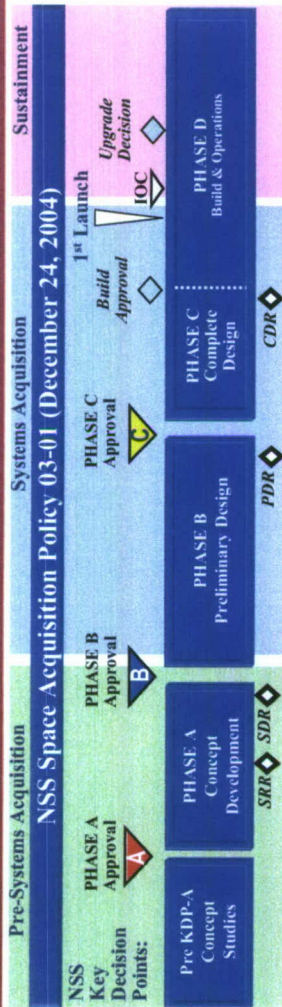
  ❖ Making time a KPP is a value statement of the Customer

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"Back to Basics" Air Force Directive

- **Relevant elements of the March 14, 2007 Memorandum by the Under Secretary of the Air Force***

  ❖ Delivery times should be based on a Time Certain Development principle

  – A specific time frame must be established in which a specific block of capability will be fielded, starting at **Key Decision Point B (KDP B)**

  ❖ Program estimates should be based on an 80% confidence level by KDP-B

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What is Time Certain Development?

Acronyms:

CDR: Critical Design Review
DOD: Department of Defense
DODI: Department of Defense Instructions
IOC: Initial Operational Capability
NSS: National Security Space
PDR: Preliminary Design Review
SDR: System Design Review
SRR: System Requirements Review

Notes:

* DODI 5000.2 has a single acquisition life cycle model only. The chart compares the DOD model to the NSS' *Small Quantity System Model*, showing the first acquisition increment.

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A Little Hair-Splitting...

Pre-Systems Acquisition | **Systems Acquisition** | **Sustainment**

Concept Refinement | Technology Development | System Development & Demonstration | Production and Deployment | Operations and Support

Milestones: Technology Development Approval (A) | System Development & Demonstration Approval (B) | Low-Rate Initial Production Approval (C) | IOC (Initial Operational Capability)

80% ("High Confidence") Estimate

"Time-to-Need"

- **The DAPA text says "Adjust program estimates to reflect high confidence, defined as a program with an 80% chance of completing development at or below estimated cost"**

  ❖ What they probably mean is **budget** the program at the 80/20 level (i.e., having an 80% chance of completion at or below budget,) and not adjusting the estimate

 ❖ We need to separate the **estimation** considerations from **budgeting** considerations (See next slide)

Elements of the Total Cost Framework*

- **Software Cost (Effort) estimation is usually done via the use of Cost Estimation Relationships (CERs) – See next slide**

  ❖ The process yields a **point estimate** on the basis of

    – Software size
    – Cost Drivers
    – Development Life Cycle Model
    – Work Breakdown Structure or Architecture

  ❖ The comprehension of cost estimation risk sources yields a **probability distribution**

    – CER error
    – Cost Driver/Configuration uncertainty

- **Budgeting/Funding decisions**

  ❖ Effort loading is based on **affordability**
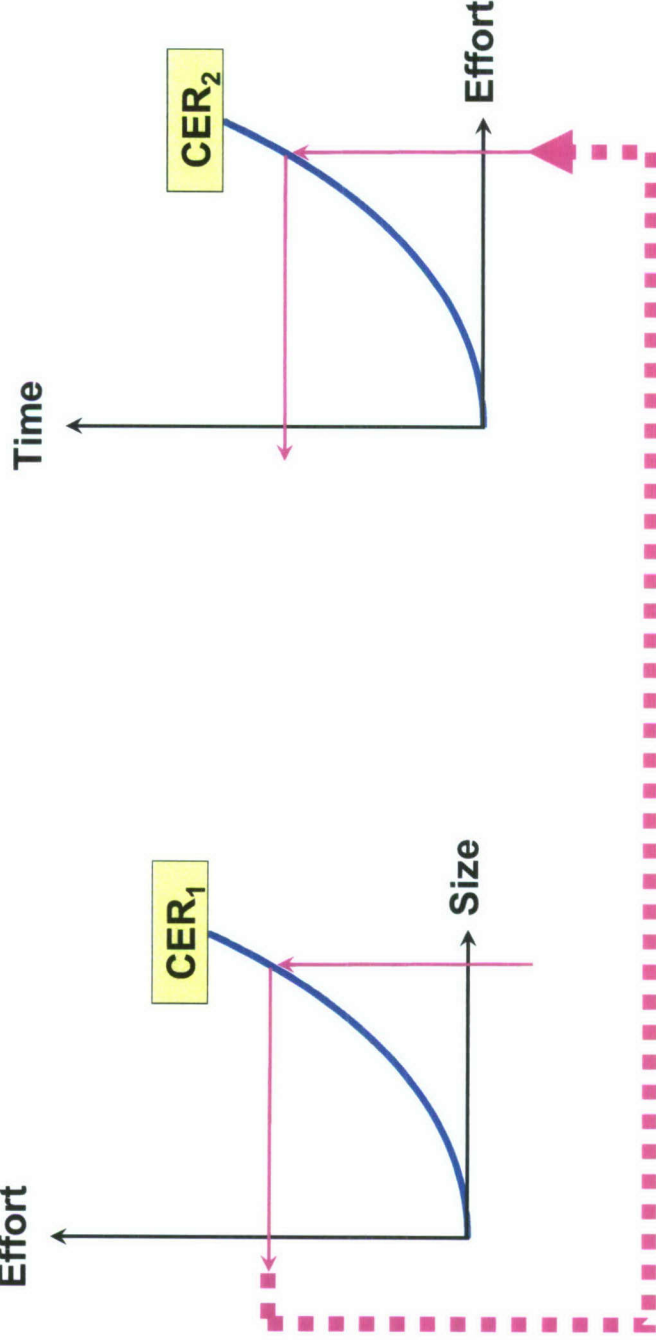
    – Uncertainty arises from phasing, inflation, etc.

* Discussion is based on [Covert 2007]
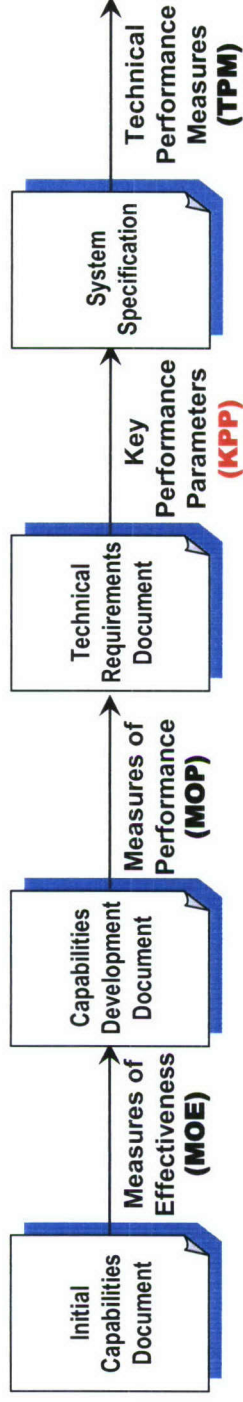
Detour #1 - CER Basics for Software Estimation

Step 1: Effort Estimation
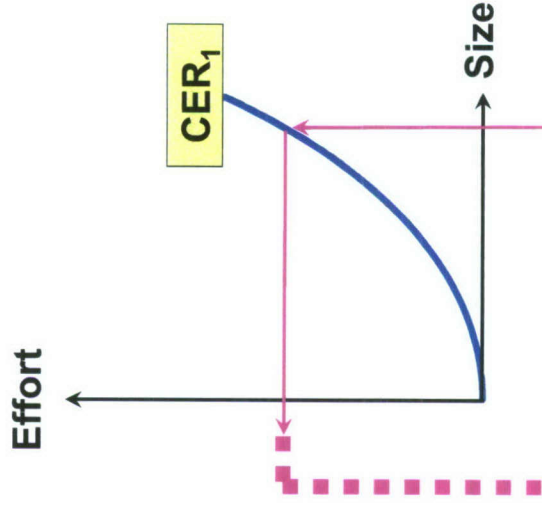
Step 2: Time (Schedule) Estimation

Detour #2: Introduction to Key Performance Parameters

Flow diagram:
- Initial Capabilities Document → **Measures of Effectiveness (MOE)** → Capabilities Development Document → **Measures of Performance (MOP)** → Technical Requirements Document → **Key Performance Parameters (KPP)** → System Specification → **Technical Performance Measures (TPM)**

Measures of Effectiveness (MOE)

A qualitative or quantitative measure of a system's performance or a characteristic that indicates the degree to which it performs the task or meets a requirement under specified conditions.

Measures of Performance (MOP)

A quantitative measure of the lowest level of physical performance (e.g., range, velocity, throughput) or physical characteristic (e.g., height, weight, volume, frequency).

Key Performance Parameters (KPP)

Minimum or threshold attributes or characteristics considered most essential for an effective military capability; KPP's are not considered for further trade-off.

Technical Performance Measures (TPM)

Selected key, high-risk, performance requirements or design characteristics. The System Specification and the KPPs are used to negotiate the selected TPMs with the System Developer Contractor.

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Perspectives on Making Time a Key Performance Parameter

- **Customer Perspective**
  - ❖ If something is important then the best, forceful way to express its importance is to designate it as a KPP [Boudreau 2003]
  - ❖ The DAPA recommendation represents the same philosophy: Having the availability of a capability on time is important, hence make time a KPP

- **Acquisition Management Perspective**
  - ❖ The previous slide illustrates that the term "performance" supposed to refer to attributes of the objective system and not to the performance of the contract
    - – In reality, Cost and Schedule are neither "performance parameters" nor "variables" (Like in CAIV and SAIV)
      - – **Cost and Schedule are constraints**

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Everything is Always Important …

- **There has always been an "Important Issue of the Day"**

  ❖ CAIV (Cost As Independent Variable)

  – "In establishing realistic objectives, the user shall treat cost as a military requirement" [DODI 2003]

  ❖ R-TOC (Reduction of Total Ownership Cost)

  – "Serious consideration must be given to elevating TOC to KPP status" [Boudreau 2003]

  ❖ Mission Success

  – "Re-establish mission success (quality) as primary criteria in managing acquisition process" [Young 2003]

- **Selecting Time as a Key Performance Parameter is not helpful**

  ❖ KPP's are more than simply important planning considerations

  – Note how they become manageable on a practical level via the decomposition into supporting Technical Performance Measures

  – Their progression and the progression of the dependent TPM's are closely tracked and monitored during development

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Perspectives on Time Certain Development

- **Contractor perspective on Time Certain Development:**
  - ❖ Still only means schedule constraints, regardless of the noble intentions

- **Prevailing misconceptions:**
  - ❖ It is Timebox Development
  - ❖ It is SAIV (Schedule As Independent Variable)

- **It is neither:**
  - ❖ Both approaches are based on adaptive project management principles
    - – They might be helpful but do not ensure success
  - ❖ The main challenge is still providing a "High Confidence" Estimate at the front-end
    - – Adaptive or agile project management strategies can only provide minor corrections and/or the renegotiation of customer requirements during the course of development

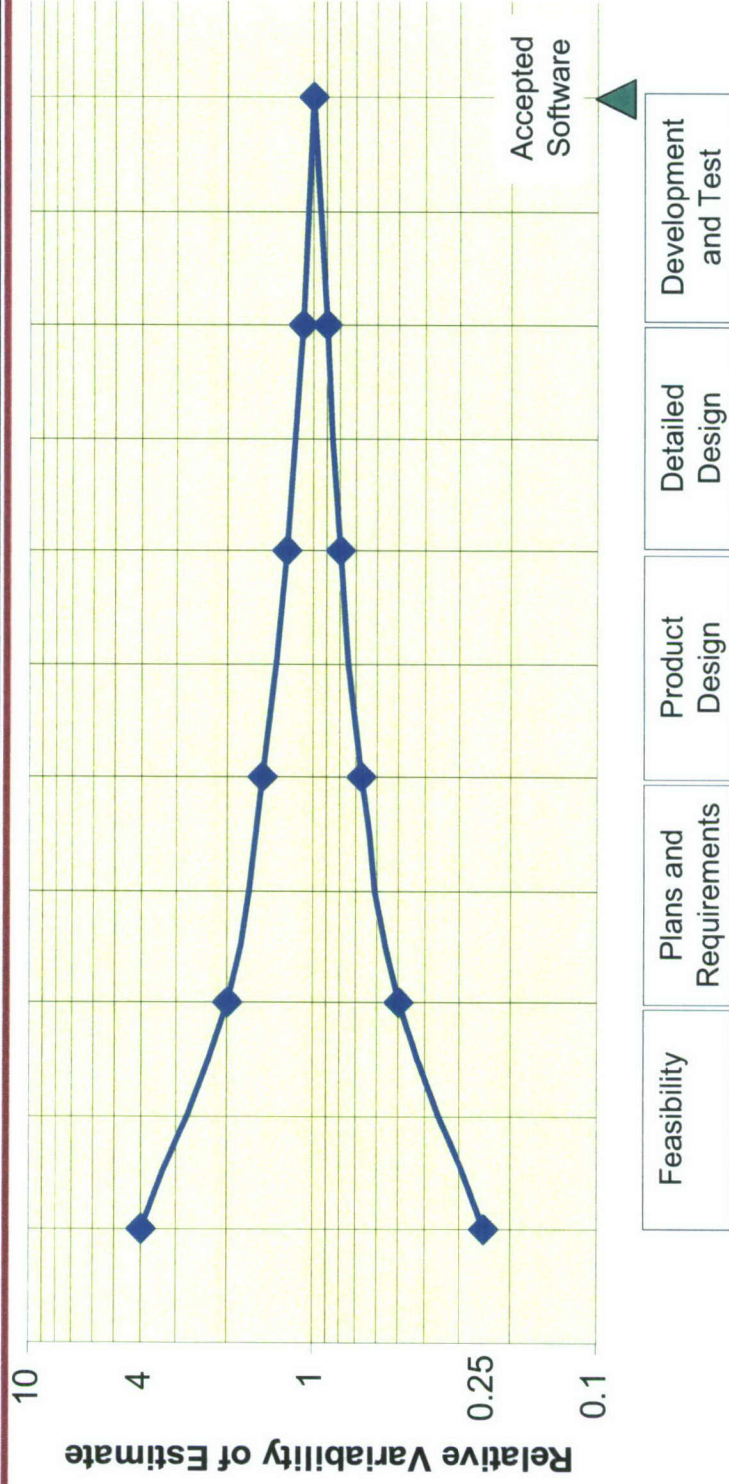Key issue: Renegotiating requirements without jeopardizing the mission!

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Software Size Is Always Chronically Underestimated

- **Software cost estimation's "dirty little secret":**

  ❖ For most parametric cost estimation models software size is a major driver but size estimation accuracy is not part of the published cost estimation model accuracies

    – Software Cost Estimation Model accuracy data assumes a 100% software size accuracy

- **Estimating software size is actually quite difficult**

    – The following Actual/Estimate KSLOC (Thousand Source Lines Of Code) data was published for three different datasets [Bozoki 2005]:

Datasets* Of Examined Programs	Actual Size Range for Accepted Software (KSLOC)	Ratio of Mean Actual/Estimate KSLOC Values
A	6 - 71	1.61
B	45 - 320	2.38
C	8.7 - 877	1.49

Note that actual program details are hidden due to confidentiality reasons

Cone of Uncertainty in Software Cost Estimation*

Software Development Life Cycle Phases

Relative Variability of Estimate (y-axis): 10, 4, 1, 0.25, 0.1

Phases: Feasibility | Plans and Requirements | Product Design | Detailed Design | Development and Test → Accepted Software

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Accuracy Dependency on the Development Life Cycle Phase

- E.g., the COCOMO II (Constructive Cost Model) family of models*
  distinguishes between three different estimation
  strategies/objectives associated with life cycle phases:

  ❖ **Early prototyping** stage
    – The objective is to estimate the cost of early risk-reduction activities.

  ❖ **Early design** stage
    – The objective is to explore the cost of alternative software/system
      architecture options and the concept of operations.

  ❖ **Post-architecture** stage
    – The objective is to estimate the cost of actual development for the
      software product.

- **Caveats:**

  ❖ The number of available data-points for calibration (and
    consequently the estimation accuracy) is low for the early stages

  ❖ The models can only be used successively, and their use is
    dependent on facts learned and design decisions made in prior
    stages

Source [Boehm 2000]

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Risks of Cost Estimation Risk-reduction Approaches

- **The common "recipes" to reduce estimation risks:**

    ❖ Pay close attention to calibration issues:
    - Chose models that were calibrated with more data points
    - Carry out a local calibration of the model
    - Try using models that were calibrated in the appropriate domain

    ❖ Estimate on lower levels of the Work Breakdown Structure and do a bottom-up integration of estimates
    - This approach can also build on the domain calibration idea

- **Caveats:**

    ❖ Estimating on lower levels improves the component estimation accuracy but creates difficulties for estimating integration efforts
    - Estimation of developmental phasing* of concurrent efforts is not in scope for parametric models
    - Methods to estimate integration, test, and rework efforts are not as accurate and effective as the methods used for estimating routine development activities

    ❖ Past organizational performance is no guarantee of future success
    - With respect to organizational capability (see [Ferguson 2002])

    ❖ Past organizational performance might be irrelevant
    - E.g., the estimation of the impact of technology risks (See next few slides)

Not to be confused with phasing concerns related to budgeting

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Technology Readiness*

- **Technology Readiness Assessment (TRA) is a key element of the Milestone B decision**

- **TRA Process**

  ❖ The Program Manager is responsible for identifying Critical Technology Elements (CTEs)

  ❖ A TRA is conducted by an independent entity on the basis of the information provided by the Program Manager

    – The result of the TRA is a TRL (Technology Readiness Level) rating for all identified CTEs

- **Per DOD 5000.2, the entry criteria for entering into System Development & Demonstration Phase (Milestone B decision) is TRL ≥ 6 for all CTEs**

  ❖ The equivalent National Security Space Acquisition Policy statement is that the entry criteria for entering into System Preliminary Design (KDP-B decision) is TRL ≥ 6 for all CTEs
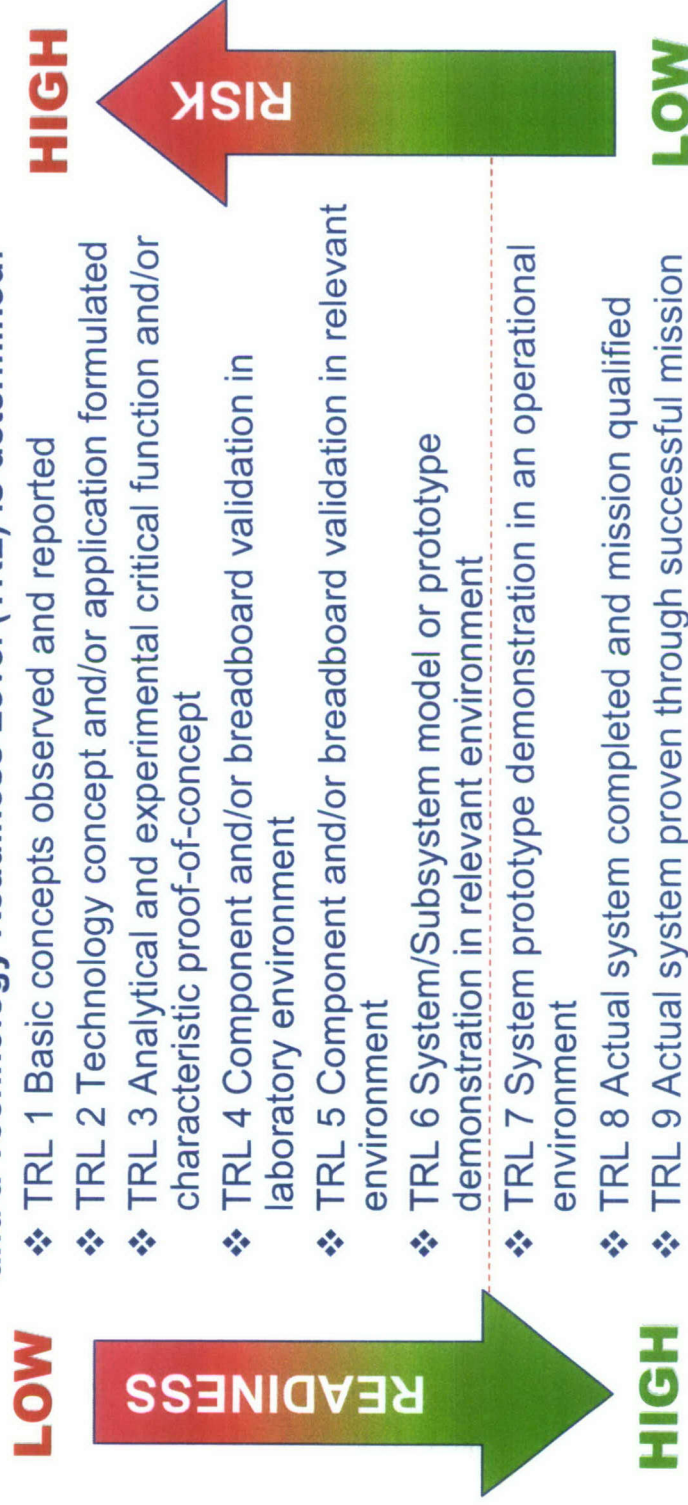

Reference: [DUSD 2005]

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Technology Readiness Levels*

- The program's Critical Technology Elements are assessed and a Technology Readiness Level (TRL) is determined:

  ❖ TRL 1 Basic concepts observed and reported
  ❖ TRL 2 Technology concept and/or application formulated
  ❖ TRL 3 Analytical and experimental critical function and/or characteristic proof-of-concept
  ❖ TRL 4 Component and/or breadboard validation in laboratory environment
  ❖ TRL 5 Component and/or breadboard validation in relevant environment
  ❖ TRL 6 System/Subsystem model or prototype demonstration in relevant environment
  ❖ TRL 7 System prototype demonstration in an operational environment
  ❖ TRL 8 Actual system completed and mission qualified
  ❖ TRL 9 Actual system proven through successful mission

LOW ←——— RISK ——— **HIGH**

LOW ←——— READINESS ——→ **HIGH**

Reference: [DUSD 2005]. Rating scheme is applicable to both hardware and software.

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Implications for Time Certain Development

- **TRLs represent milestones of the technology development life cycle in the Technology Development phase**

  ❖ Essential characteristics of this life cycle:

    – Technology development is a learning process:
      - **Steps are strictly sequential – can not be executed concurrently**
      - **Success of steps depends on the success of preceding steps**
    – Most activities are un-precedented
      - The routine, repetitive part is insignificant
   - No historical data; estimation must be based on heuristics

The presence of any technology uncertainty jeopardizes the accuracy of estimates obtained at KDP-A

The Iron Triangle in Theory

Requirements
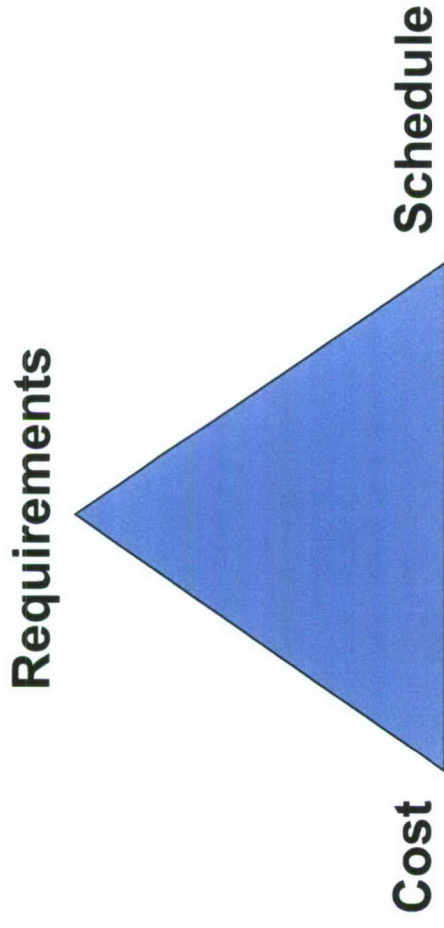
Cost

Schedule

- **Fallacies:**
  - ❖ Pick two of the Cost, Requirements, Schedule triad and negotiate the third factor
  - ❖ This "negotiation" can be carried out as a seamless trade
    - – During early project negotiations
   - – Continually, during project execution

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The First Fallacy of the Iron Triangle is that it is a Triangle ...

Requirements

Cost

Schedule
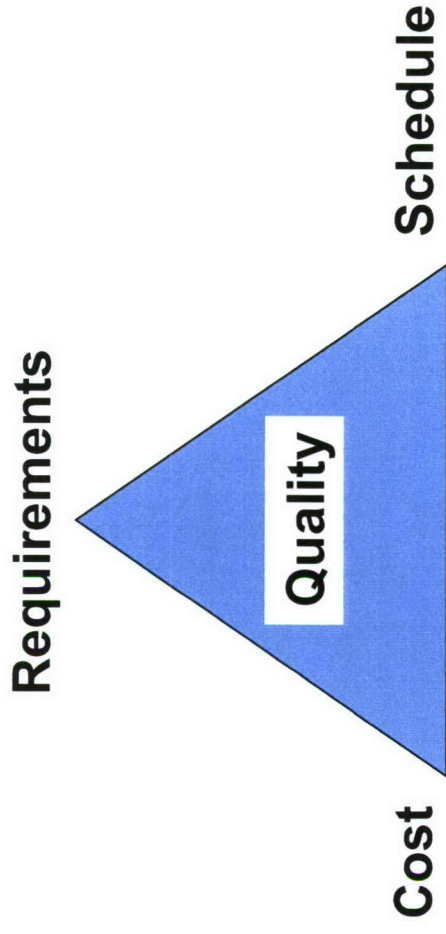
Quality

- Abusive approaches to quality with serious estimation consequences:
    - ❖ It is viewed "free" or it is "expected" without quantification
- **Quality must be explicitly considered and quantified**
    - ❖ Quality is integral part of mission success
        - – However, it is difficult to determine the cost of quality or explicitly design for quality
        - – It is more than just cost of non-conformance, as Crosby defined it in his seminal book [Crosby 1980]

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- Crosby - Cost of Quality or Price of Nonconformance:

  ❖ External failure cost – customer-related

  ❖ Internal failure cost – scrap, rework, re-inspection, re-test, etc.

  ❖ Inspection (appraisal) cost – evaluating quality

  ❖ Prevention cost – reviews, surveys, education, training, etc.

- What else is needed?

  ❖ Added effort and diligence to encompass illities during the architecting process

  ❖ Quality must be "engineered-in"

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The Fallacy of Seamless Size-Effort-Time Trade
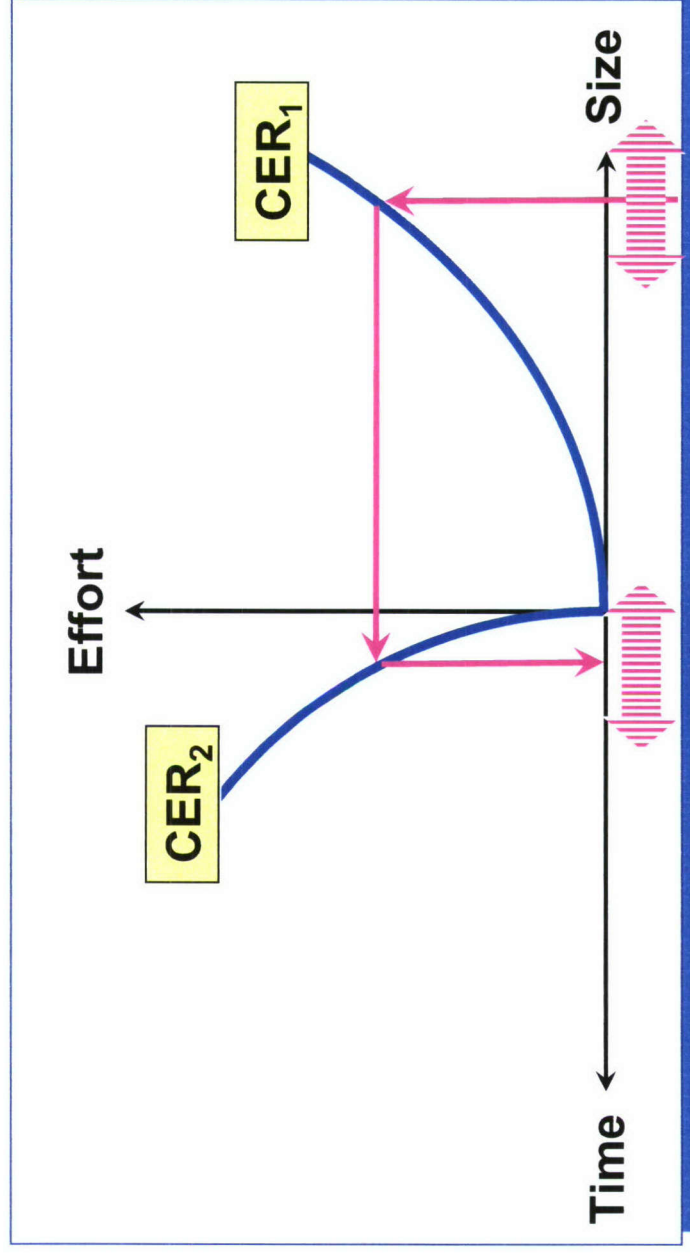
However, in reality there are only a finite number of architectural options.

Architectural Options (Solution Sets) and Cost*
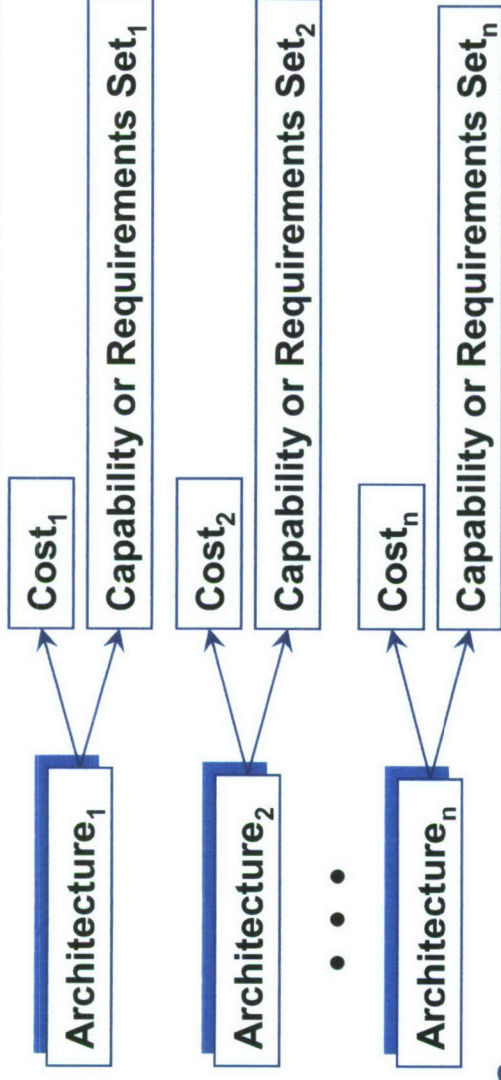
- **Consequences**
  - ❖ During initial estimation:
    - – For the *Cost – Schedule – Capabilities* trade we have only a few options
  - ❖ During development:
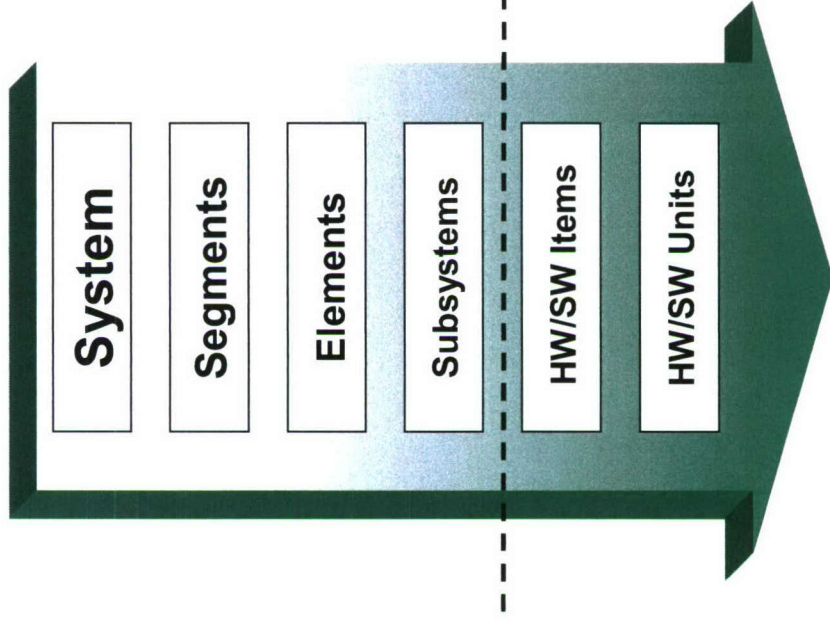   - – Requirements can not always simply "dropped" in order to maintain cost or schedule objectives

* Diagram is based on [Rice 2000]

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Space-Specific WBS (Work Breakdown Structure)

Typical WBS Hierarchy

- System
- Segments
- Elements
- Subsystems
- HW/SW Items
- HW/SW Units

Example (Ground Thread)

Satellite

Ground, Space, User, Launch

Ground Elements: Mission Control, TT&C, Support

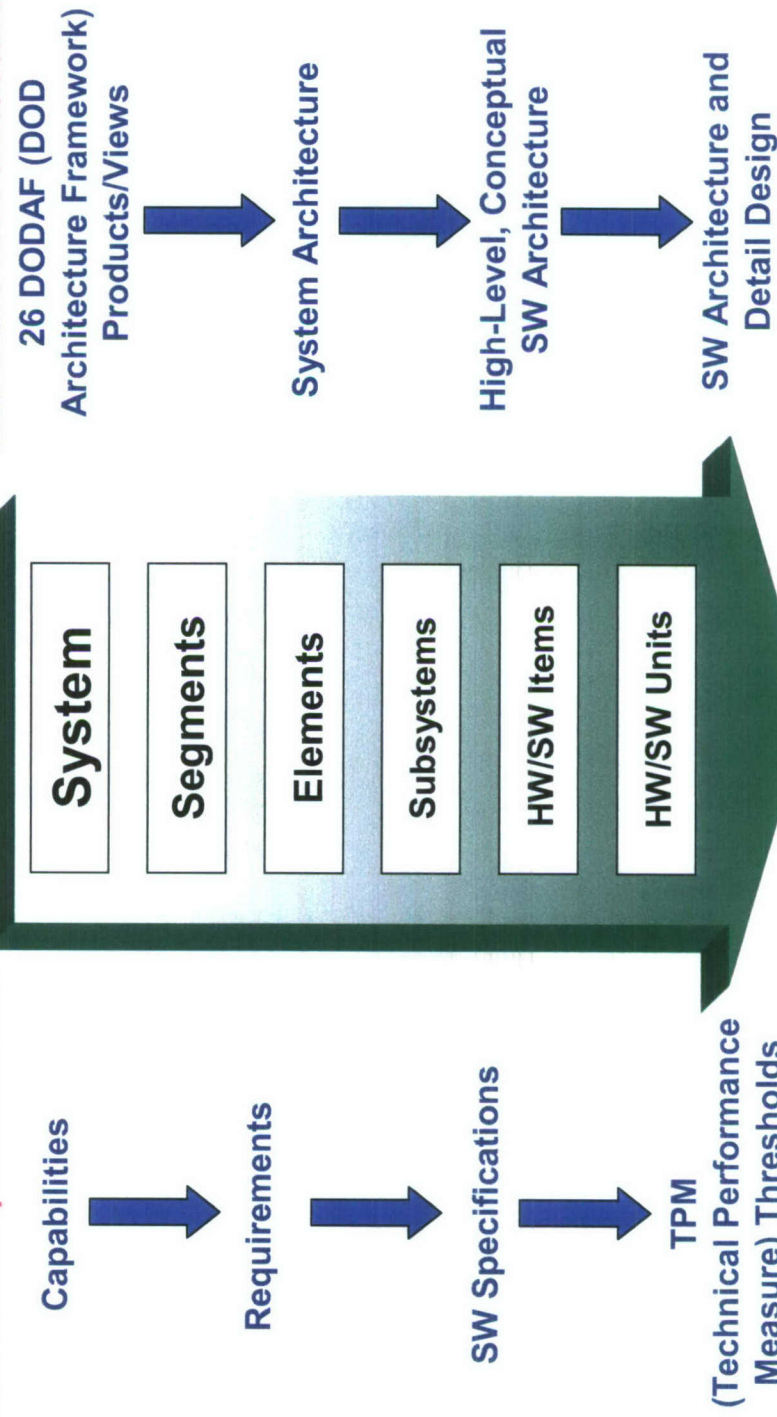**Mission Control Subsystems**: Master Control, Ground Antenna Control

Master Control SW Items: Mission Planning, Payload Planning

Mission Planning SW Units: Generate Timeline, Define Vehicle Configuration, Plan Orbital Maneuver

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Space-Specific Software Discussion

There are Requirements and there are Requirements…

… and there is Architecture and there is Architecture.

Capabilities → Requirements → SW Specifications → TPM (Technical Performance Measure) Thresholds

System / Segments / Elements / Subsystems / HW/SW Items / HW/SW Units

26 DODAF (DOD Architecture Framework) Products/Views → System Architecture → High-Level, Conceptual SW Architecture → SW Architecture and Detail Design

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Capabilities vs. Requirements

- **Note the language of the acquisition domain: "Deliver useful military capability"**

  ❖ Customer needs are expressed in form of capabilities

    – The intent is not to impose unnecessary, technical implementation constraints on the Contractor

- **However, development contracts are written with "Requirements" in mind**

  ❖ During the source selection process the Government Program Office must understand, interpret, and translate customer needs into tangible, feasible requirements and communicate them to the competing contractors

  ❖ These requirements are the basis for developing detailed **system specifications** by the contractor

  ❖ These requirements are also used for developing **cost/schedule estimates**

    – **Caveats:**

      – It is impossible to provide accurate cost and schedule estimates for delivering abstract capabilities

      – During estimation the capabilities must be mapped into solution sets (designs) as the previous slide showed

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The Experts' Voices

- **Barry Boehm [Boehm 1981]**
  - ❖ "Whatever the strengths of a software cost estimation technique, there is no way we can expect the technique to compensate for our lack of definition or understanding of the software job to be done. Until a software specification is fully defined, it actually represents a range of software products, and a corresponding range of software development costs."

- **George Bozoki [Bozoki 2005]**
  - ❖ "SSM (Software Sizing Model) can be employed in any phase of the software development cycle in which the user can partition the software project into modules or components whose operational and functional characteristics are defined."

- **Steve McConnell [McConnell 2006]**
  - ❖ "Meaningful commitments are not possible in the early, wide part of the Cone. Effective organizations delay their commitments until they have done work to force the Cone to narrow."

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Conclusions

- **Time Certain Development – as an acquisition strategy – poses very difficult engineering challenges**
  - ❖ Even state-of-the-art estimation and engineering approaches could not support successful implementation for large programs

- **Accurate size estimation requires the full comprehension of the implementation consequences of "illities"**
  - ❖ Such analysis can only be based on a detailed and adequately documented software architecture

- **The root-cause of the dissatisfaction with the performance of the Acquisition System lies with misstated or misunderstood, unrealistic, and mismanaged expectations**
  - ❖ While improving estimation accuracy is certainly beneficial, further improvement efforts should focus on deeper understanding of engineering practices and the human dimensions of the Acquisition System

- **Topics for further discussion**
  - ❖ What the proper solution would be to the problems described in the DAPA Report
  - ❖ How to really address the concerns of the combatant commanders

Final conclusion: Estimating the unprecedented remains a black art....

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Acronyms

CAIV	Cost As Independent Variable
CER	Cost Estimation Relationship
COCOMO	Constructive Cost Model
DAPA	Defense Acquisition Performance Assessment
DOD	Department of Defense
IOC	Initial Operational Capability
KPP	Key Performance Parameter
KSLOC	Thousand Source Lines of Code
MOE	Measures of Effectiveness
MOIE	Mission-Oriented Investigation and Experimentation
MOP	Measures of Performance
PPBE	Planning, Programming, Budgeting, and Execution
R-TOC	Reduction of Total Ownership Cost
SAIV	Schedule As Independent Variable
TPM	Technical Performance Parameter
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
USAF	United States Air Force
USC	University of Southern California
WBS	Work Breakdown Structure

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